FY-07 Mendenhall Postdoctoral Fellowship Program – Proposed Research Opportunity

Title: PALEOHYDROLOGY AND PALEOCLIMATE OF DESERTS FROM STUDY OF PAST WETLAND DEPOSITS

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I. BACKGROUND

Deserts are known to be highly sensitive to climate fluctuations, and are expected to respond strongly to future climate change. A knowledge of the effects of past climate fluctuations since last glacial conditions will greatly improve our understanding of desert responses, but effects of past climate fluctuations are difficult to determine because most desert deposits are difficult to date and have poorly known climate linkages. An exception is aquatic-environment deposits such as lake deposits, which have been studied in detail in the semiarid western U.S. (Utah, northern Nevada, and Oregon). Wetland deposits are an additional climate-sensitive class of arid-land deposits for which only a handful of detailed studies exist. They are generally termed ground-water discharge deposits to encompass a variety of marsh, wet meadow, spring, and wet playa settings. This research opportunity seeks to better understand this important class of deposits by studying representative types with respect to timing, aquatic environment, characteristics of the deposits, and climatic controls on paleohydrology. Key questions include: (1) Is the timing of ground-water discharge deposits a function of paleohydrology driven by climate variations or is it caused by more localized factors?; (2) To what temporal scales of climate variability do ground-water discharge deposits respond, from seasonal to interannual?; (3) What components of aquatic environments are controlled by local factors (e.g., rock chemistry along the groundwater flow path or in the discharge area) as opposed to regional (e.g., dust flux, geomorphic setting) or climatic factors?

II. DESCRIPTION OF THE RESEARCH OPPORTUNITY

Geologic mapping by USGS during the past five years in the Mojave Desert has demonstrated the presence of dozens of deposits created by groundwater discharge. Reconnaissance dating by ^{14}C and OSL reveals that many deposits are latest Pleistocene in age and ostracode identifications show that they represent a wide range of aquatic conditions. Deposits also range in areal extent, duration of deposition, and landscape position. Similar deposits associated with the carbonate aquifer of southern Nevada have been studied by Quade and co-workers, and also are known from southern Arizona.

Previous studies suggest significant regional differences in the timing of wet periods in the desert Southwest.

The post-doctoral research will formulate a plan to select Mojave Desert ground-water discharge deposits, date them by multiple methods to determine times of paleohydrologic events, and infer aquatic environments from deposit characteristics including sedimentology, stable isotopes, and fossil ostracodes and gastropods. Study of the Mojave Desert examples will permit better understanding of paleohydrology and paleoclimate of the Mojave Desert and comparisons with deposits in adjacent deserts to discern regional influences. Paleohydrologic results derived from the widely distributed groundwater-discharge deposits can be tied to ongoing studies of lake deposits and pack-rat middens to evaluate past local and regional climatic variability since the last glacial maximum. In addition, this information will extend and broaden the ongoing analysis of a more detailed and longer lake record based on older sediments of pluvial Lake Manix in the Mojave.

III. RELEVANCE AND TIMELINESS

The Science Strategy for Geologic Division identifies a need to define the range and rates of natural climate variability in order to assess the historic human influence on climate and to predict the effects of climate changes. The primary method for this work is to refine records of past climate change and its effects on the landscape. This research opportunity will help define the magnitude, extent, and impact of past climate change by studying a little-studied class of aquatic deposits. In particular, this research should yield higher temporal resolution records for a highly sensitive desert setting.

The research will build on the results of Mojave Desert studies funded by several programs, which have fleshed out the problem in terms of mapping the many deposits and conducting reconnaissance dating and environmental studies.

Research Proposal

Jeff Pigati
November 30, 2005

Research objectives

Background

As continental ice sheets waxed and waned over much of North America during the last glacial period, major reorganizations of the atmosphere, biosphere, and hydrosphere left behind large footprints in the deserts of the American Southwest. During full glacial times, plant communities were often displaced 1000 m or more downslope, large lake systems were present where only seasonally-filled or dry playas exist today, perennial springs and wetlands were common, and megafauna thrived in areas that are now too dry to support them. Decades of research has been directed at quantifying the magnitude and timing of past climate change in the Southwest through the analysis of paleoenvironmental and paleoclimatic archives. For example, pollen and macrofossils preserved in packrat middens have been used to decipher plant migration and speciation through time (e.g., *1-5*), sedimentological, biological, and isotopic data have been used to reconstruct Pleistocene lake levels (*6-11*), and faunal assemblages have been used to constrain past climate regimes (*12, 13*).

Another important source of paleoenvironmental data, particularly for the deserts of the American Southwest, is a group of deposits known as groundwater discharge or "spring" deposits (*14*). Spring deposits form in arid environments as water tables rise and breach the ground surface during periods of enhanced effective precipitation. In addition to providing an important water source for local fauna, emergent water tables also support hydrophilic vegetation, which in turn acts a as natural catchment system for eolian sediments. The interplay between emergent water tables, ecological and biological systems, and wind-derived sediments results in a unique and complex depositional environment that contains information on the timing (age of deposits) and magnitude (faunal and ostracode assemblages, isotopic data) of past climate change (Fig. 1). Spring deposits also clearly demarcate the position of past water tables on the landscape, which provides direct evidence of past hydrologic conditions.

Spring deposits have been identified in all four of the major deserts of North America (Chihuahuan, Great Basin, Mojave and Sonoran), but have been investigated in detail at only a handful of localities (*15-21*). This vast and largely untapped reservoir of paleoenvironmental information could potentially be used to reconstruct changes in climatic and hydrologic conditions over both time and space by systematically investigating a number of sites that are similar in age but spread out over a large geographic area. This approach allows us to distinguish between local and regional forcing mechanisms that are often difficult to separate. It also allows us to identify and place temporal constraints on changes in large-scale atmospheric and hydrologic systems that have affected the American Southwest since the last glacial maximum.

Research plan

The Mojave Desert provides an ideal venue for such an opportunity. Encompassing more than 65,000 km^2 in southeastern California, western Arizona, southern Utah, and southwestern Nevada, the Mojave represents a transitional desert between the lower-elevation Sonoran Desert to the south and the higher-elevation Great Basin to the north. Although much of the Mojave

Desert is extremely arid today, it supported a large, interconnected lake system, as well as numerous springs and wetland systems, during the last glacial period (*22*).

Approximately 130 localities that contain spring deposits have recently been identified in the Mojave Desert by David M. Miller and colleagues during mapping efforts supported by the U.S. Geological Survey (Fig. 2). For this study, I propose to conduct a systematic investigation of the stratigraphy, chronology, faunal remains (vertebrate and invertebrate), and isotope geochemistry of a selected number of these deposits in order to (1) constrain the timing and magnitude of paleohydrologic changes in the Mojave Desert, (2) place constraints on the timing of changes in large-scale atmospheric circulation patterns over the American Southwest during the last glacial to interglacial transition, (3) better understand the magnitude of natural variability in water table elevations in desert biomes in the American Southwest through time, and (4) improve our understanding of desert response to past climate change in order to facilitate management of this fragile ecosystem in light of future climate change.

In order to achieve these goals in the proposed two-year time period of the Mendenhall postdoctoral fellowship, the scope of the proposed work is focused on the following tasks:

- Establish a stratigraphic framework for selected Mojave spring deposits
- Determine the ages and rates of deposition of the selected spring deposits
- Reconstruct paleoenvironments using sedimentology, fossil ostracodes and gastropods, vertebrate remains, geochemistry, and stable isotopic analysis
- Evaluate the paleohydrologic response of spring systems to regional climate change in the context of other proxy records from the Mojave Desert and surrounding areas

<u>Stratigraphic framework</u>

Detailed stratigraphic analysis must be completed at each site in order to place the final geochemical, isotopic, and faunal assemblage results in a firm temporal context. At each site, this will entail mapping the aerial extent of deposits, determining the number of units present, digging multiple soil pits (unless natural exposures are available), completing detailed descriptions of sediment characteristics (grain size, texture, mineralogy) for each unit, and collection of appropriate samples for age control, geochemical and stable isotope analysis, and ostracode and gastropod analysis. Protocols for establishing stratigraphic frameworks are well known and have been used previously by P.I. Pigati while working on spring deposits elsewhere in the American Southwest (*19*).

<u>Chronologic framework</u>

The methods for determining the age(s) of spring deposits at a given site will be determined primarily by the material that is available for radiometric dating. Plant macrofossils and some species of terrestrial gastropods typically yield reliable ^{14}C ages when recovered from spring deposits. These will be the preferred materials to use for age control when present. ^{14}C dating of aquatic gastropods and ostracodes may be necessary in their absence, but should be avoided if possible because of problems associated with "hard-water" effects[1]. Optically-stimulated luminescence (OSL) dating may be suitable for dating eolian sediments incorporated

[1] "Hard-water effects" is a phrase that is used to describe the discrepancy between the ^{14}C content of some water bodies and atmospheric carbon. Although there are many potential causes of such a discrepancy, including water-rock interaction and ^{14}C decay along groundwater flowpaths, hard-water effects always results in ^{14}C ages that are too old. The magnitude of the error is often variable and difficult to quantify.

in the spring deposits and could be used when materials for ^{14}C dating are not available (see attached letter of support from S. Mahan, Director of the OSL laboratory, USGS, Denver CO).

Paleoenvironmental reconstruction

Spring deposits contain paleohydrologic information in their position on the landscape, fossil (vertebrate and invertebrate) assemblages, isotope geochemistry, and sedimentology. P.I. Pigati has experience with identifying and interpreting gastropod assemblages, measuring stable isotope ratios ($\delta^{18}O$, $\delta^{13}C$) of groundwater carbonate and fossil shells, geochemical analysis (% carbonate), and sedimentological analysis. The amount of effort and time that will be afforded each of these techniques will depend on the type of sediments and fossil encountered, as well as their preservation state and potential usefulness in reconstructing paleoenvironmental conditions.

Evaluation of paleohydrologic response

We will first determine the level of temporal coherency of the response of local hydrologic systems to regional climate change based on radiometric dating and paleoenvironmental reconstructions. We will then evaluate the composite paleohydrologic record in the context of other proxy records from the Mojave Desert and surrounding areas with these key questions in mind:

- Were there multiple periods of elevated water tables in the Mojave Desert during the Late Pleistocene and Holocene?
- During a given time period, was the paleohydrologic response synchronous over the entire Mojave Desert and, if so, what does that imply about past sources of precipitation?
- If the response over the Mojave was asynchronous, what were the patterns of elevated water tables in both time and space?
- Do the different temporal and spatial responses give us insight into paleohydrologic response to a specific event, such as migration of the polar jet stream across the region during the Late Pleistocene, or did the paleosprings respond more to localized forcing mechanisms?
- Is there a significant time lag between changes in climate and hydrologic response? In other words, do the ages of the deposits accurately reflect the timing of climate change?

Links to USGS science strategy

The research project that I propose addresses Goals 4 and 5 of the science strategy of the Geologic Division of the U.S. Geological Survey. Goal 4 of USGS Circular 1172 states…

> "Defining the range and rates of natural climate variability is the key both to assessing the historic human influence on climate and to predicting the effects of climate changes. The instrumental record of climate is restricted largely to the last hundred years and is grossly inadequate to understand the dynamics of the modern climate. *The only way to extend this meager climate record is through continued detailed paleoclimatological analysis of the historic and geologic past.* The USGS is working to help define the magnitude, extent, and impact of past climate change as well as the frequency of climate variability. Specifically, there are two areas in which the GD will assume a leadership role in the U.S. Global Change Program: (1) continental- and *regional-scale*

reconstruction of key past climates, using a combination of terrestrial and marine paleoclimate records…

The results of the proposed project will support Goal 4 of the USGS Circular by (1) extending the known climate record well beyond the historical record, in fact through the Holocene and into the Pleistocene, and (2) establishing a regional-scale reconstruction of past climatic and hydrologic conditions encompassing most of the Mojave Desert.

Goal 5 of Circular 1172 states…

"The scientific basis for ecosystem management, particularly the role of geology in sustaining or restoring ecosystems, is emerging as a major, multidisciplinary scientific challenge for the GD. It is now widely recognized that the living resources of ecosystems have a spatial organization imposed upon them by the geologic framework of the region and that *geologic processes…significantly influence ecosystem evolution and vitality on time scales of days to decades*. Moreover, the geologic record contains valuable clues to the structure, history, and behavior of ecosystems…

The results of the proposed study will support Goal 5 of the USGS Circular by addressing questions regarding the natural variability in the hydrologic response of desert biomes to changes in climate. For example, are historical variations in ground water elevations in the Mojave significant when viewed from a paleo-perspective? Are extreme variations that can be measured on an interannual and decadal cause for alarm? Or do they fall within the bounds of the natural cycle? Such information will allow for more informed and better management of the important and fragile ecosystem of the Mojave Desert that are within a few hours drive of nearly 40 million people.

How and where research is to be conducted

I propose to conduct this study based out of the USGS office in Denver, CO. All field work will take place in the Mojave Desert, sample preparation work will take place at USGS facilities in Denver, and extractions for ^{14}C and stable isotopic analysis will be conducted at the University of Arizona's Desert Laboratory in Tucson (see rationale below). I plan to work closely with researchers in the Denver, Tucson, and Menlo Park offices of the U.S. Geological Survey, as well as with other non-USGS personnel working in the Mojave region, throughout the course of the project.

The first step of the proposed project will be to identify sites that are promising in terms of location, geomorphic expression, local catchment characteristics, sedimentology, and potential for radiometric dating based on the initial surveys already completed. Spring deposits form in a variety of locations in desert landscapes where groundwater is forced to the surface, such as along fault scarps, changes in bedrock lithology, and the distal ends of alluvial fans. Because the overall goal of the proposed study is to determine the paleohydrologic response across the Mojave Desert to climate change during the Late Pleistocene and Holocene, it is critical that the age and depositional settings are similar for the systems chosen for study. To that end, it will be necessary to categorize all potential sites by catchment properties, such as area, relief, and maximum elevation, and then focus our investigations on sites with similar characteristics in order to minimize differences in local responses to the same event.

Keeping this in mind, we will select approximately 15-20 sites for an initial reconnaissance visit to determine those that are most suitable for detailed investigation. These initial site visits will consist of taking photographs, field notes, and digging a limited number of soil pits to determine the number of units present, the presence or absence of fossils (vertebrates and invertebrates), preservation state, and potential for radiometric dating. We anticipate that the reconnaissance work will likely take ~1 day per site (total of 3-4 weeks in the field).

We will then choose a total of 12-15 sites for detailed investigation. At each site, we will conduct a systematic evaluation of the spring deposits that will include:

- mapping the aerial extent of the spring deposits
- determining the number of units present
- constructing detailed stratigraphic profiles
- taking photographs
- collecting samples for radiometric dating (^{14}C, OSL)
- collecting samples for geochemical and isotopic analysis

The amount of field time required at each site will obviously depend on the complexity of the site and the number of units present. However, we estimate that this task, on average, will take approximately one week of field time per site (a total of 12-15 weeks of field time over the two year period of the project).

Basic preparation of samples for geochemical, isotopic, and radiometric dating will be conducted at USGS facilities in Denver. This will include wet chemistry techniques involving sample rinsing and filtration, treatment with dilute acid (HCl) and base (NaOH) solutions, and storage for additional processing. Laboratory work involving extractions of ^{14}C from organic and inorganic samples for radiometric dating, as well as final preparations for geochemical and isotopic measurements, will be performed at the University of Arizona's Desert Laboratory in Tucson. The Desert Laboratory contains operational facilities for ^{14}C dating and stable isotope analysis, as well as an extraction system that is used for processing old (35-55 ka) samples for ^{14}C dating, which can be used if necessary. There is no fee for P.I. Pigati to use these facilities per an agreement with Dr. Jay Quade, Director of the Desert Laboratory (see attached letter of support). Lodging costs are minimal ($25 per week) through the Desert Laboratory.

There are several advantages of using the facilities at the Desert Laboratory for ^{14}C dating. First, the extraction systems were designed, constructed, and maintained by P.I. Pigati over the past several years. These systems were specifically designed for isolating and extracting ^{14}C from organic and inorganic material and, therefore, are reliable in terms of getting accurate, reproducible results. Moreover, the amount of time that will be saved if P.I. Pigati processes and extracts samples for ^{14}C and stable isotopic analysis is significant and will allow us to complete a large amount of chronological work within the two year period of this proposed project. It will also alleviate demand on the existing USGS analytical facilities in Reston, VA. Such an extensive dating effort would simply not be possible if we send our ^{14}C samples out for external processing.

The scope of field and laboratory work required during Year 2 will be determined largely on the progress achieved during Year 1. We suspect that we will need to revisit some of the sites from Year 1 for verification, as well as to collect additional samples for radiometric dating or geochemical analysis. We will also investigate a limited number of new sites to fill in spatial or temporal gaps left during the previous year's work.

Names of Research Advisors
David M. Miller, USGS – Menlo Park, CA
Marith Reheis, USGS – Denver, CO
Chris Menges, USGS – Tucson, AZ
Darrell Kaufman, Northern Arizona University, Flagstaff, AZ

Required scientific facilities
Wet chemistry facility, Denver CO

- Analytical balance, fume hood, filtration system, clean water source (preferably 18.2 MΩ Milli-Q), binocular microscope

University of Arizona's Desert Laboratory, Tucson AZ

- Existing systems are operational and adequate for proposed work

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Figure 1: Example of a sequence of spring discharge deposits in the Mojave Desert. The resistant surface cap is underlain by alternating units of organic rich clay and fossil-bearing silts and fine sands that are typical of these deposits in the American Southwest.

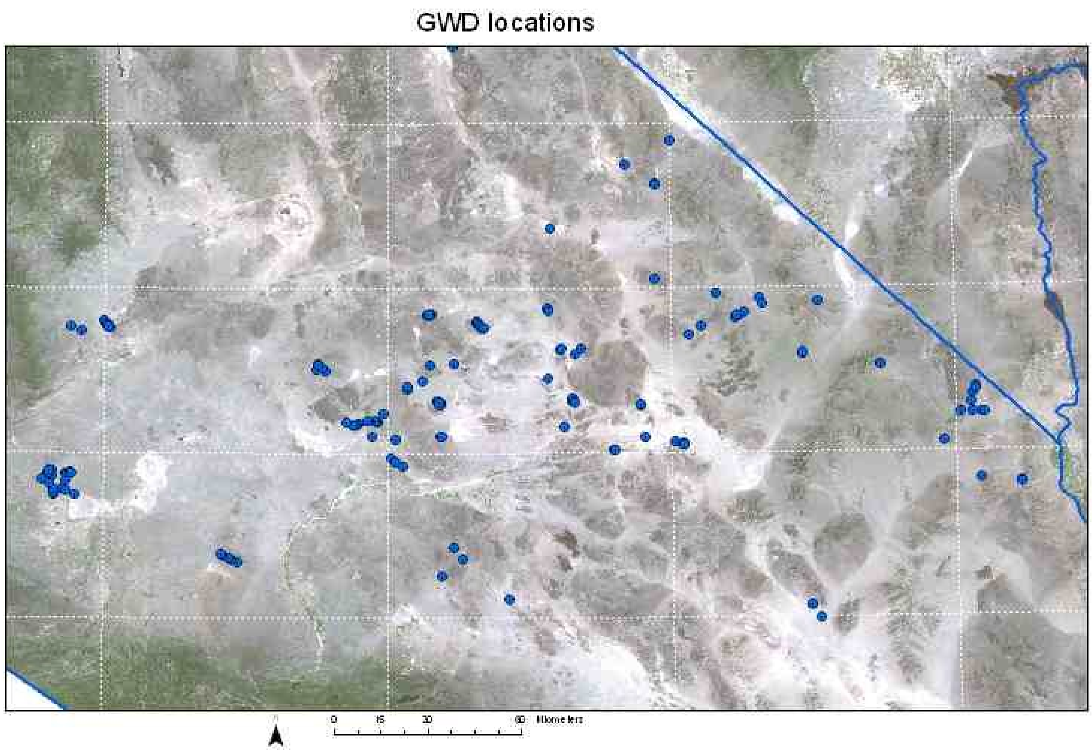

Figure 2: Location of spring discharge deposits in the Mojave Desert identified by D.M. Miller, USGS (blue dots). The southern wedge of Nevada is bounded by the blue lines in the upper right portion of the figure.

Anticipated operating expenses

		Unit cost	FY 2006	FY 2007
Field expenses	Air travel (Denver-Las Vegas) 5 tickets per yr	$300	$1500	$1500
	Government vehicle 1st yr 8 weeks; 2nd yr 8 weeks	$150/month; $0.35/mile	$2000	$2000
	Gas, food, lodging 1st yr 8 weeks; 2nd yr 8 weeks	$300 per wk	$2400	$2400
	Maps, air photos	--	$500	$500
Office expenses	Desktop computer with basic software packages	--	$2500	--
Laboratory expenses	Wet chemistry (Denver) Glassware, acids, misc items	--	$500	$500
	Air travel (Denver-Tucson) 3 tickets per yr	$300	$900	$900
	Lodging (Desert Lab) 6 weeks per year	$25 per wk	$150	$150
	^{14}C extractions (Desert Lab) 1st yr n=50; 2nd yr n=25	$10	$500	$250
	AMS measurements (NSF-AZ) 1st yr n=50; 2nd yr n=25	$125[1]	$6250	$3125
	OSL dating (USGS, Denver lab) 1st yr n=0; 2nd yr n=10	$750	--	$7500
	Stable isotope analysis (Tucson) 1st yr n=100; 2nd yr n=50	$15	$1500	$750
	Geochemical analysis 1st yr n=50; 2nd yr n=25	$75	$3750	$1825
	Grain size analysis 1st yr n=50; 2nd yr n=25	$25	$1250	$625
	Ostracode analysis (Flagstaff) 1st yr n=50; 2nd yr n=25	$50	$2500	$1250
Conference	Travel, registration	--	--	$2000
Publication of results	Journal page costs for anticipated peer reviewed papers (n=2)	--	--	$2000
Misc.	Field/office/lab equipment	--	$500	$500
TOTAL			**$26,700**	**$27,775**

[1] Per agreement with NSF-Arizona AMS facility. Analytical cost includes $\delta^{13}C$ measurement that is used to correct measured ^{14}C ages for isotopic fractionation.